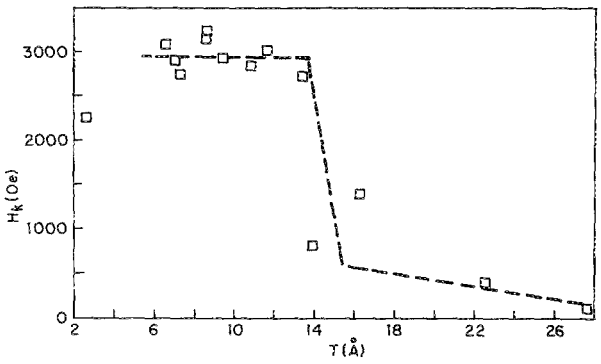

FIG. 2. Dependence of anisotropy field H_K vs Co thickness in Pt/Co LS.

alloys with a vertical magnetic easy axis have been reported in the literature.[9] Assuming an alloy contribution to the total magnetization, we estimate the width of the alloyed region to be ~4 atomic layers.

In summary, both Pd/Co and Pt/Co LS exhibit a perpendicular easy axis of magnetization. The origin of the the anisotropy appears to be different for each. An interface anisotropy is responsible in Pd-LS, and interfacial alloying is implicated in Pt-LS.

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Summary Abstract: Scanning electron microscope with polarization analysis studies of magnetic materials

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The study of magnetic films and surfaces has been aided immensely by the development of various electron-spin-dependent analytical techniques. Spin-dependent versions of photoemission, inverse photoemission, secondary electron emission, Auger spectroscopy, and electron diffraction are all macroscopic techniques that yield information about a material's surface magnetic properties.[1] Much of the interest in these materials, however, lies in understanding their microscopic magnetic structure. In order to further our knowledge of magnetic microstructure, we have used the results of earlier polarized electron work to develop a technique that can probe the microstructure of thin films and surfaces. The technique, scanning electron microscopy with polarization analysis (SEMPA), combines the high spatial resolution of a scanning electron microscope with spin polarization analysis of the secondary electrons.[2] Because the secondary electron polarization is directly proportional to the specimen magnetization in the region probed by the electron beam,[3] SEMPA can directly image the sample's magnetic microstructure with the spatial resolution of the scanning electron microscope (10 nm).

Our SEMPA apparatus consists of an ultrahigh vacuum scanning electron microscope, electron optics which collect and transport the secondary electrons from the sample to the detectors, low-energy diffuse scattering electron-spin polarization analyzers, and associated electronics that can digitally scan the incident electron beam, collect signals, and record images. An ultrahigh vacuum microscope is required because the secondary electrons, with escape depths of several nanometers are relatively surface sensitive. Unlike conventional scanning electron microscopy where all of the secondaries, including those from any surface contamination, contribute to the topographic contrast, only secondaries emitted directly from the magnetic material contribute to the SEMPA signal. Our scanning electron microscope uses a field emission electron source which produces a 1-nA beam of 50-nm diameter at the specimen.

In order to simplify the modification of a scanning electron microscope for SEMPA, a new type of electron-spin polarization analyzer was developed. The analyzer is based upon the spin-orbit interaction in the elastic scattering of polarized, 150-eV electrons from an evaporated polycrystalline gold film.[4] A major advantage of this particular detector is that it is easier to add to a microscope and simpler to operate than more conventional detectors, while being just as efficient as a spin analyzer. One detector can measure the

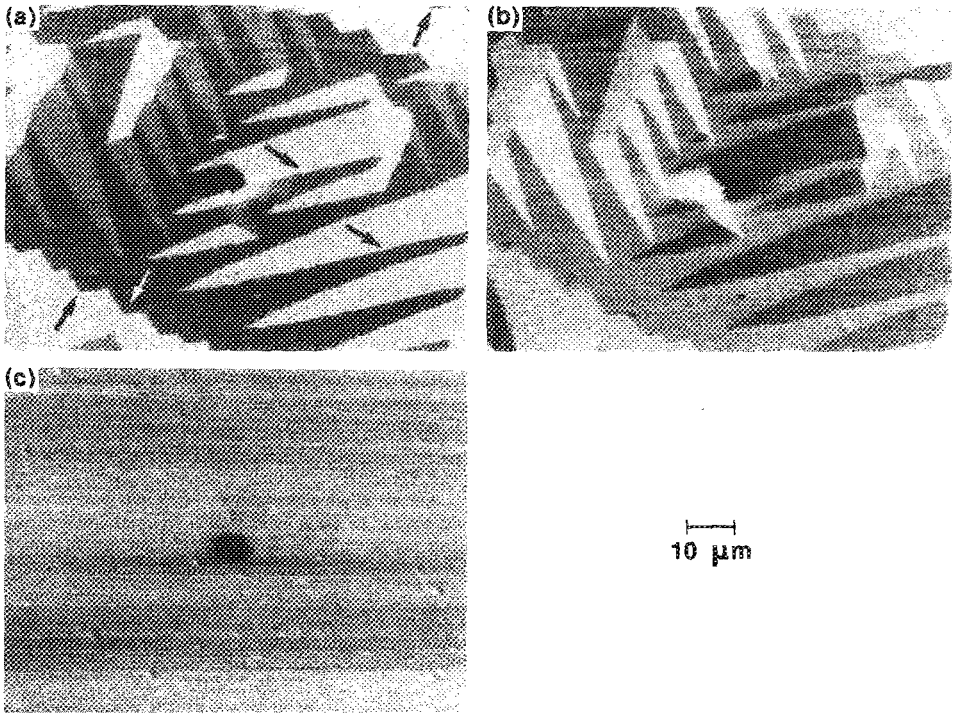

FIG. 1. Magnetic domain structure of an Fe–3% Si crystal. The magnetization projected onto the two detector axes is shown in (a) and (b). The intensity is shown in (c). Arrows indicate the magnetization directions.

two transverse components of a polarized electron beam. By electrostatically deflecting the electron beam by 90°, the longitudinal component is changed to a transverse component and can also be measured. Thus the magnitude and direction of the polarization vector can be completely determined. In our apparatus one detector measures the two in-plane components of the specimen magnetization while a second, orthogonal detector measures the magnetization perpendicular to the sample surface.

An example of a SEMPA measurement is shown in Fig. 1. The sample is an Fe–3% Si single crystal that was cut 4° off of the [100] direction. The sample was prepared by ion bombardment followed by heating to 500 °C. The figure shows the in-plane components of the sample magnetization projected onto the two orthogonal analyzer axes in Figs. 1(a) and 1(b) and in Fig. 1(c) the spin-independent intensity. All three images are obtained simultaneously using one detector. Domains with four different magnetizations are observed, because there are two easy magnetization axes ([100] directions) in the specimen surface plane. By adding the measured components, the magnetization vector can be obtained. The four possible magnetization directions are shown in Fig. 1(a).

This example illustrates some of the unique and extremely useful features of the SEMPA technique. First, because the polarization is directly proportional to the magnetization, the magnetization magnitude and direction may be determined. Second, a spin-independent topographic image is obtained simultaneously with the magnetic image, so that topographic and magnetic structures can be separated and their interaction studied. Third, the contrast in the magnetic image, compared with more conventional techniques, is relatively high. And finally, SEMPA has the highest spatial resolution of any technique for imaging the magnetic microstructures of opaque specimens. Our best resolution so far has been about 50 nm and is solely limited by the diameter of the incident electron beam.

In addition to Fe crystals we have also successfully looked at magnetic domains in Permalloy thin films, CoNi recording media, and in metallic glasses of various compositions. In the future we intend to exploit the surface sensitivity of SEMPA by studying the microstructure of magnetic films that are only a few monolayers thick. We also plan to combine SEMPA with a scanning Auger microprobe in order to study the relationships between chemical composition and magnetic microstructure.

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